FOOT REACTION FORCES DURING LONG DURATION SPACE FLIGHT

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INTRODUCTION

Musculoskeletal changes, particularly in the lower extremities, are an established consequence of long-duration space flight despite exercise countermeasures [1, 2]. It is widely believed that disuse and reduction in load bearing are key to these physiological changes, but no quantitative data characterizing the on-orbit movement environments currently exist. Here we present data from the Foot Experiment (E318) regarding astronaut activity on the ground and on-orbit during typical days from 4 International Space Station (ISS) crew members who flew during increments 6, 8, 11, and 12.

METHODS

All subjects gave informed consent to participate in this IRB-approved experiment. Fourteen total channels of data were collected at sampling rates between 8 Hz and 1024 Hz, including seven channels of EMG, four channels of joint angle data, two channels of in-shoe ground reaction force (GRF) and a marker channel for event recording. Data were typically collected for between 6.5 and 11.8 hours of activity during 4 days on Earth and 4 - 7 days in-flight. Instrumentation was built into a Lower Extremity Monitoring Suit custom-made for each subject. The hardware was used to collect data for entire workdays while crew members performed their daily tasks. All data were analyzed by custom routines written in MATLAB (Mathworks Inc). DXA and MRI scans and maximum joint torques were taken pre- and post-flight to quantify any bone mineral density (BMD), muscle volume, and muscle strength changes that occurred during the flight.

RESULTS

The foot force data indicated that on-orbit treadmill exercise countermeasures resulted in lower forces than during similar activities on Earth; there was a 25% reduction compared to walking on Earth (0.89 BW vs. 1.18 BW) and a 46% reduction compared to running on Earth (1.28 BW vs. 2.36 BW). The used ranges of motion of the hip and the knee joints were significantly reduced on the ISS [3]. There was an increase in the isometric action on-orbit at the expense of concentric and eccentric actions. Tibialis anterior showed a significant increase in the net neural drive (NND) and the duration of activation on-orbit vs. Earth whereas the medial gastrocnemius showed a decrease in NND on-orbit. Average monthly BMD losses in the femoral neck, total hip, and lumbar spine regions for the astronaut subjects were 0.71%, 0.81% and 0.83%, respectively.

CONCLUSIONS

Bone and muscle loss occurred in these crewmembers on the ISS despite exercise countermeasures. The muscles spanning the knee and the hip joints are operated at altered lengths and velocities which may contribute to functional losses in the muscles concerned reflected by loss of strength and muscle volume. The global picture provided by the lower daily force loads, the reduced loading during on-orbit locomotion, together with altered use of lower extremity joints and muscles present strong evidence that the “dose” derived from exercise needs to be increased. Such an increased dose could be obtained by increasing the load in the treadmill subject load device (SLD), increasing the speeds used on the ISS treadmill, or by other novel exercise paradigms. The design of future exercise countermeasure equipment and prescriptions should address these issues in order to safeguard bone health during future long-duration missions to the moon and Mars.

REFERENCES

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ACKNOWLEDGMENTS

This work was supported by NASA cooperative agreement NCC 9 153.